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Briquette Compacting in Container with a Small Taper Angle

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Abstract. The aim of the study is to determine the strain state of a briquette during the compacting process. Modeling is performed with the use of a software system for the compaction process. Gurson's yield condition for a plastically compressible continuum is applied. A comparison of the known experimental data is made, and it shows good qualitative convergence results.

INTRODUCTION

Briquetting of granular media is used in many industries, among other things, for the compaction of charge materials [1], chip scraps, man-made formations [2] of metallic powders and granules [3].

Roll briquetting of granular media is the most productive treatment process [4, 5, 6]; however, sometimes the obtained briquettes are not large enough, this being caused by specific conditions of gripping by roller systems. The production of large briquettes makes one to use plunger briquetting. A theoretical description of noncompact material compaction in a container was carried out by analytical methods [7] and numerical modeling [8, 9], including the finite element method [10, 11].

The aim of this study is to evaluate the effect of the press tool configuration on the strain state of a briquette produced by plunger molding.

ENGINEERING PROBLEM STATEMENT

When granular media are compacted in a container, special techniques can be applied in order to increase the process efficiency. A certain role is played by the shape of the container cavity. In the simplest case, this shape is a cylindrical surface (Fig. 1a). The granular medium 1 is placed in the container cavity 2 closed from below by a spacer 3, and material compression is performed by the downward motion of a punch 4. If it is necessary to extrude the workpiece, the tooling is placed on the support ring 5 (Fig. 1b), and first the spacer, then the workpiece 1 are pressed out.

One of the problems arising from this procedure is that, during pressing out, slip cracks may appear at the boundary of contact with the container cavity; this zone is symbolized by A. Their occurrence is due to the workpiece elastic expansion after removal of compression stresses from the workpiece contour. The process is accompanied by an increase in the workpiece diameter relative to the container cavity diameter. The displacement of particles induced by elastic deformation in the zone free from the action of compressive stresses may cause destruction of the workpiece surface layers in the form of cracks stretching along the tangential coordinate. Cracks occur in workpieces the material of which is too non-plastic.

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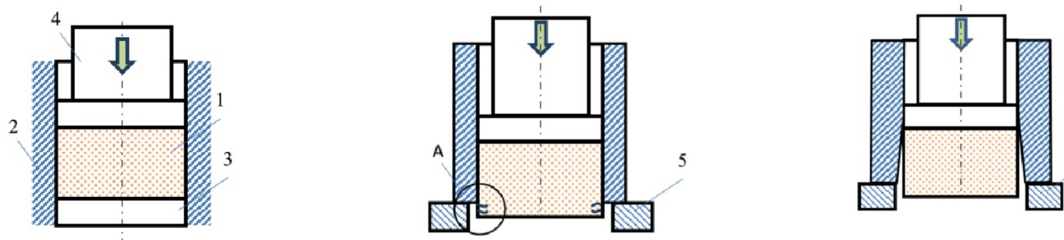

(a) (b) (c)

FIGURE 1. Scheme of granular medium pressing in a container with a cylindrical cavity (a), the appearance of slip cracks in the pressing operation (b), and a variant of pressing out through a conical cavity (c): 1 – the workpiece; 2 – the cavity, 3 – the spacer; 4 – the punch; 5 – the support ring

In order to avoid cracks of this kind, tooling is used in the form of a two-part container. In this case, the workpiece removal is carried out by extraction from the cavity after tool disassembly, rather than by pressing. Another option is using a container with the cavity made with a slight taper. In this case, the workpiece extrusion is carried out towards the conical surface expansion (Fig. 1c), and this eliminates the appearance of large stress gradients. However, in this case, the workpiece surface may become conoidal, rather than cylindrical. In many cases, this can be tolerated, for example, when obtaining briquettes for subsequent metallurgical processing [12].

The replacement of the cylindrical shape by the conoidal one in the briquetting operation itself leads to a change in the stress state. Therefore, in what follows, we consider the process of briquette shaping in a conical tool, not pressing out.

COMPUTATIONAL SIMULATION

ABAQUS was used to simulate the granular medium compaction process in the following formulation of the problem. The material to be deformed is porous copper. The hardening curve corresponds to the copper grade M1 with the following approximation: $\sigma_s = 80 + 283**\varepsilon^{0.118}$. The finite element type used is quad-dominated, the number of the finite elements is 213, and the problem is axisymmetric.

The medium model (i.e. porous metal plasticity model) is available in the interface of the software module, and it is described by Gurson's yield condition [13], which was used by a sufficiently large number of researchers [14, 15 etc.]. The yield condition is constructed on the scheme of spherical pore deformation in an ideally plastic material, and it is operable at a small value of porosity.

The program module recommends using the following parameters of the flow equation: $q_1 = 1\ldots1.5$; $q_2 = 1$; $q_3 = q_1^2 = 1\ldots2.25$. The solution uses $q_1 = q_2 = q_3 = 1$, the initial relative density of the material is 0.9 (i.e. the relative porosity is 10%), the initial ratio of the deformation center height h_0 to the radius R is 2, the relative punch displacement is $\Delta h/h_0 = 0.1$. Such deformation is small, but the obtained solution makes it possible to understand which stress-strain state parameters change if the cylindrical surface of the container is replaced by a conical one.

DISCUSSION

Figure 2a shows the problem solution in the presence of a cylindrical cavity in a container and under the action of the friction coefficient equal to 0.4. Indeed, if the material prepared for remelting is subject to briquetting, the contact surface lubricants are unlikely to be used for reducing the friction coefficient. The right half of the deformation focus is displayed. As can be seen from the solution obtained, the highest density is reached in the upper right corner of the cylinder longitudinal section, the lowest density being in the lower right corner. As noted in [16], the size of this zone depends on the briquette dimensions ratio, the friction coefficient and the ratio of the volume and shear hardening characteristics of the medium to be consolidated. Along the cylinder axis, the density can reach a maximum.

(a) (b)

FIGURE 2. The distribution of relative density RD for cylindrical (a) and conical (b) briquettes at a friction coefficient of 0.4; the color key is common for the two versions

Figure 2b shows a solution with a small taper of the container wall, characterized by an angle of 2°. In order to avoid punch jamming in the container having a converging cavity, a cylindrical portion of the cavity is provided in the upper part, with a punch moving along this portion. It is seen that the patterns of relative density distribution remain the same, but the zone of maximum density becomes larger. In addition, in other zones the density values themselves prove to be higher. The exception is the zone adjacent to the lower left corner of the deformation focus.

The explanation of this phenomenon lies in the analysis of the displacement field for these two pressing cases. Figure 3a, b shows the horizontal displacement fields U1. In the absence of friction, the radial displacement components must be close to zero. This fact was verified by performing the procedure of solving the problem. However, it is obvious from Fig. 3a that, when the friction is high, the displacements are large enough and they range between -0.54 and 0.40, which is about 5% of the reduction Δh.

(a) (b)

FIGURE 3. The distribution of the radial displacement component U1 during the pressing of cylindrical (a) and conical (b) briquettes with a friction coefficient of 0.4

The figure shows that the distribution of radial displacements differs by the presence of two extremes located, respectively, in the upper and lower parts of the deformation center. The extremum in the upper part describes the presence of a maximum modulo of radial displacement towards the center, and the extremum in the lower part is the maximum displacement towards the periphery.

When there is a taper (Fig. 3b), the location of the extrema remains the same, but the range of displacement fluctuations decreases. At the same time, it should be noted that the figure shows a combined effect of two factors on the distribution of the parameters, namely, friction and the taper. At the next stage of the calculations, we decided to eliminate the effect of one of the factors by equating the friction coefficient to zero.

Figure 4a shows the distribution of the vertical component of the displacement vector for a briquette with a conical surface in the pressing process when there is no friction. Here, it is clear that, despite the presence of a conical surface, the displacements decrease from top to bottom with a very weak dependence on the radial coordinate.

In the transition to pressing with a high friction coefficient (Fig. 4b), the displacement vector component U2 becomes dependent on the radial coordinate. Vertical displacements decrease closer to the periphery and increase in the central layers. Thus, a more significant factor for the formation of a strain state is friction rather than the taper of the container cavity. At least, this applies to low taper values, at the level of 2°.

(a) (b)

FIGURE 4. The distribution of the vertical component U2 of the displacement vector for a briquette with a conical surface when pressed without friction (a) and with a friction coefficient of 0.4 (b)

CONCLUSIONS

The tapered working surface of the container makes it possible to facilitate the pressing of briquettes out of the press tool cavity. The calculations of the stress-strain state, performed by the finite element method, have shown that the presence of a taper at a level of 2° leads to a redistribution of volumetric deformations. Briquette volumes with high density increase. The calculations performed for different values of the friction coefficient have shown that friction remains the decisive factor for creating inhomogeneous density distribution.

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